High Pressure Exposed Detonating Cord Detonator System

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CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] None.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

REFERENCE TO A MICROFICHE APPENDIX

[0003] Not applicable.

FIELD OF THE INVENTION

[0004] The invention relates to detonating systems, and more particularly to detonators for explosive systems which include detonating cord exposed to hostile environments including high-pressure fluids.

BACKGROUND OF THE INVENTION

[0005] In oil well perforating operations, it is common practice to use well perforating guns whose explosive components and shaped charges are directly exposed to well bore fluids and pressures. Typically, these explosive components may be carried along a flexible or semi-flexible strip of metallic carrying member and may be locked to the carrying member and affixed through holes bored in the strip, thus directly exposing the shaped charges to the well bore environment.

[0006] Perforating guns of this type may be referred to as expendable perforating guns in the sense that, when the explosive charges are fired, the carrying member is destroyed or separated into numerous small pieces by the explosion of the shaped charges and may fall to the bottom of the well as small debris. Such expendable carrier perforating guns have the advantage that the maximum sized shaped charges for a given diameter of well

can be installed, as opposed to conventional hollow carrier shaped charge perforating guns. Hollow carrier shaped charge guns carry a plurality of shaped charges which must fit within a carrier tube which protects them from the borehole environment.

[0007] The expendable perforating guns are typically run into a well on an electrical wireline, which provides both mechanical support and electrical connections for firing the perforating gun. An electrically fired detonator is typically connected to the wireline. A secondary explosive detonating cord is typically ignited by the detonator and extends the length of the perforating gun to sequentially fire each of the individual shaped charges carried by the perforating gun.

[0008] The explosive components of a typical perforating gun therefore comprise a detonator, a length of detonating cord, and a plurality of shaped charges. The borehole environment affects these components in various ways. Detonators are very sensitive to borehole fluids and typically will not fire if the fluids enter or contact the detonator. The shaped charges will not function properly if they are filled with borehole fluids. Shaped charges may be fitted with seals which exclude borehole fluids from the explosive charges. Detonating cord functions properly when exposed directly to the borehole pressure and fluids along most of its length, as long as one end of the cord is protected from the fluids where explosive transfer from the detonator is required.

[0009] Various other operations in oil and gas wells use exposed detonating cord either as the primary explosive charge or for explosive transfer from a detonator to other charges. Such operations include exploration, production, stimulation and pipe recovery operations. For example, a back off operation may use a detonator and detonating cord without additional charges such as shaped charges. The detonating cord itself provides the explosive forces needed in the back off operation. The combination of a detonator and

exposed detonating cord may be used in all these operations. In these operations, it is important to protect the detonator and the explosive transfer connection to the detonating cord from borehole fluids.

SUMMARY OF THE INVENTION

[0010] The present invention provides a detonator system for detonating cord in well operations in which a detonator and its coupling to the detonating cord is protected from the well environment. The system includes a firing head having a sealed detonator chamber for a detonator and a booster charge holder. The charge holder includes a bulkhead separating the detonator chamber from a booster charge. The firing head chamber is sealed at one end by a firing sub and at the other end by the charge holder to form an environmentally sealed chamber for a detonator. The charge holder includes a booster charge chamber for receiving a booster charge and one end of a detonating cord and positioning the booster charge adjacent the bulkhead. A fluid tight seal is provided in the booster charge chamber to restrict the flow of well fluids into the booster charge chamber.

[0011] In one embodiment, the detonator is an electrically fired detonator. The system is mechanically and electrically coupled to a surface location by a wireline. A wireline firing sub provides electrical connection from the wireline to the detonator and provides a seal at one end of the firing head chamber. The firing head chamber protects the electrical connection of the firing sub to the detonator as well as protecting the electrically fired detonator itself.

[0012] In one embodiment, the firing head is designed to be reusable and the booster charge holder is designed to be expendable. The booster charge holder includes a

chamber for receiving that portion of the detonator which contains the detonator explosive and positioning it next to the bulkhead.

[0013] In one embodiment, the firing head includes means for mechanically supporting borehole tools such as perforating guns, back off tools, etc.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Fig. 1 is a cross sectional view of an assembled detonator system according to an embodiment of the invention.

[0015] Fig. 2 is plan view of a booster charge holder according to an embodiment of the invention.

[0016] Fig. 3 is cross sectional view of the booster charge holder of Fig. 2.

[0017] Fig. 4 is a perspective view of a rubber boot according to an embodiment of the invention.

[0018] Fig. 5 is a cross sectional view of the rubber boot of Fig. 4.

[0019] Fig. 6 is a cross sectional view of a retainer cap according to one embodiment of the invention.

[0020] Fig. 7 is a cross sectional view of an alternative retainer cap according to another embodiment of the invention.

[0021] Fig. 8 is a perspective view of the retainer cap of Fig. 7.

DETAILED DESCRIPTION OF EMBODIMENTS

[0022] In the following description of embodiments, various terms such as "above" and "below" and "up hole" and "down hole" are used to indicate relative position of elements. These terms are used with reference to the normal position of the apparatus when used in a vertical borehole and are not intended to be limiting. In wells which include slanted or horizontal portions, the term up hole or above refers to the direction toward the surface

location of the well and down hole or below refers to the direction toward the end of the well farthest from the surface location. It is to be understood that the a system according to the present invention may be inverted in some applications, for example bottom fired systems, and the relative positions of the various elements may therefore be reversed or inverted.

[0023] Fig. 1 provides a cross sectional view of an assembled detonator system according to one embodiment. The primary mechanical component of this embodiment is a firing head 10. Other elements are attached to or contained within the firing head 10. An upper portion 12 of firing head 10 is generally cylindrical and has an interior chamber 14 sized to receive at least the upper portion of a detonator 16. In this embodiment, the detonator 16 is an electrically fired detonator. A firing sub 18 has a lower end coupled to the upper end of chamber 14 by threads 20. In this embodiment, the firing sub 18 is a conventional wireline firing sub. One or more O-ring seals 22 are carried on the firing sub 18 above the threads 20 and provide a fluid tight pressure seal protecting the chamber 14 from borehole fluids and pressure. As well known in the art, the wireline firing sub 18 includes an electrical conductor in its center which is insulated from the body of the sub 18. The firing sub 18 is adapted for connection to the lower end of a conventional wireline to provide an electrical connection to firing systems at the surface location of a well.

[0024] A lower portion 24 of the firing head 10 is an extension of the upper portion, but is not a complete cylinder. The lower portion 24 has a thickness of about a quarter to three-quarters that of the upper portion 12. It is effectively a half cylinder, or U-shaped section, which provides good structural strength, but is open on one side to allow easy assembly of other elements and allow dissipation of explosive forces to minimize damage to the firing head 10. One or more, in this embodiment three, holes 26 may be provided in

the lowermost portion of the firing head 10 for attachment of tools, such as back off tools or perforating guns. The lowermost section of the firing head 10 with the holes 26 may taper to a point at the bottom and be machined to provide flat surfaces for bolts to attach such tools.

[0025] A booster holder 28, shown in more detail in Figs. 2 and 3, has an upper end 30 positioned in the lower end of the detonator chamber 14. One or more O-ring seals 32 are carried on the upper end 30 to provide a fluid tight pressure seal protecting the chamber 14 from borehole fluids and pressure. The booster holder 28 is generally cylindrical and includes an upper chamber 34 and a lower chamber 36 separated by a bulkhead 38. The upper chamber 34 is sized and positioned to receive the lower end of detonator 16 which contains the actual explosive component of detonator 16. The detonator 16 explosive component is positioned adjacent to and just above the bulkhead 38.

[0026] The lower chamber 36 of booster holder 28 is sized to receive a booster charge 40 coupled to the upper end of a length of detonating cord 42. As illustrated, the booster charge 40 is positioned adjacent to and just below the bulkhead 38. A rubber boot 44, shown in more detail in Figs. 4 and 5, provides a fluid tight seal restricting the flow of well fluids into the booster holder 28 lower chamber 36.

[0027] A retainer cap 46 is threaded onto the lower end of booster holder 28 to hold the boot 44, booster charge 40 and detonating cord 42 in position in the lower chamber 36. A retaining clip 48 engages the upper end of booster holder 28 to hold its upper end 30 in sealing contact with the lower end of firing head 10 chamber 14. A screw 50 holds the retaining clip 48 in place.

[0028] In the illustrated embodiment, the detonator 16 is a Top Fire RED-III detonator sold by Jet Research Center under part number 101272595. However, the firing head 10

chamber 14 preferably has interior dimensions selected to accept a variety of detonators. No special detonator is required to withstand particular pressures or types of fluids, since the chamber 14 is sealed against both borehole pressure and fluids. In this embodiment, it is desirable that the output energy of the detonator 16 be at least equivalent to one-half gram of HMX explosive to provide sufficient energy to rupture the bulkhead 38 and provide explosive transfer to the booster charge 40. The bulkhead 38 should be of sufficient strength to withstand expected borehole pressures, since it provides part of the pressure seal protecting the detonator 16.

[0029] The detonating cord 42 may be conventional detonating cord such as that sold under the trademark PRIMACORD. In this embodiment, detonating cord 42 may contain an explosive charge of eighty grains of HE explosive per foot.

[0030] The booster charge 40 is essentially a conventional "blasting cap" type of device comprising a secondary explosive contained in a metallic tube, for example aluminum. The tube is closed on its upper end which contains the actual explosive component. Its lower end is open and contains no booster charge explosive. The upper end of detonating cord 42 is positioned in the open lower end adjacent the actual explosive component comprising booster charge 40. The open lower end is crimped onto the detonating cord 42.

[0031] Figs. 2 and 3 provide more details of the booster charge holder 28 of Fig. 1. The parts which were identified in Fig. 1 and are also shown in Figs. 2 and 3 are identified by the same reference numbers. The interior shapes of the upper chamber 34, lower chamber 36, and the bulkhead 38 between chambers 34 and 36 are shown most clearly in Fig. 3. The upper chamber 34 may be approximately cylindrical, but may have an enlarged portion 52 at its upper end to conform to the electronics portion of the detonator 16. The

lower chamber 36 has a reduced diameter portion 54 at its upper end, sized to conform to the diameter of the booster charge 40. A lower portion 56 of the chamber 36 is of larger diameter, sized to receive the boot 44 with a fluid tight fit.

[0032] Annular seal grooves 58 are provided on the outer surface of the upper end 30 of booster charge holder 28 for carrying the O-rings 22 shown in Fig. 1. An annular groove 60 is provided on the outer surface between the upper end 30 and the main body of booster holder 28 which is of somewhat smaller outer diameter than the upper end 30. In this embodiment, the retainer clip 48, Fig. 1, engages the groove 60 to retain the booster holder 28 in proper position in the firing head 10. Threads 62 are provided on the outer surface of the lower end of holder 28, to engage the retainer cap 46, Fig. 1.

[0033] The booster charge holder 28 may be manufactured from easily machined and inexpensive materials such as aluminum, copper or brass. This reduces the cost of the charge holder 28, which in this embodiment is destroyed when the detonator 16 is fired. The particular selection of material depends on the pressure in the well and types of fluids which will be encountered.

[0034] Figs. 4 and 5 provide perspective and cross sectional views of the boot 44 of Fig. 1. The boot 44 is preferably made of an elastomeric material, e.g. rubber. An upper end 64 of the boot 44 has a tapered shape and outer diameter selected to form a tight fit within the booster holder 28 lower chamber 36 lower portion 56. A lower end 66 has a smaller outer diameter, resulting in a shoulder 68 between the upper end 64 and the lower end 66. The shoulder 68 is engaged by the retainer cap 46, Fig. 1, to hold the boot 44 in the booster holder 28 lower chamber 36. The boot 44 has an inner diameter 70 at its upper end sized to form a tight fit over the booster charge 40, Fig. 1. The boot 44 has an inner diameter 72 at its lower end sized to form a tight fit over the detonating cord 42, Fig.

1. It is preferred to mold the boot 44 without a flashing on its inner or outer surfaces in order to improve the fluid tight seal between the booster charge 40, detonating cord 42, the boot 44 and the booster holder 28.

[0035] Figs. 6 provides a cross sectional view of the retainer cap 46 of Fig. 1. The cap 46 is a simple cylindrical cap having an inner threaded surface 74 on its upper end sized to mate with the threads 62 on the lower end of booster holder 28, Figs. 2 and 3. The lower end of cap 46 has an opening 76 sized to fit over the lower end 66 of the boot 44. Between the threaded portion 74 and the smaller diameter opening 76 is a shoulder 78 adapted to engage the shoulder 68 on the boot 44, Figs. 4 and 5. The outer surface of cap 46 may be knurled, if desired, to facilitate manual tightening of the cap 46 onto the booster holder 28.

[0036] Figs. 7 and 8 provide cross sectional and perspective views of an alternative retainer cap 80 which may be used in place of the retainer cap 46 shown in Figs. 1 and 6. The alternative cap 80 provides more protection for the boot 44 of Figs. 4 and 5. An upper end 82 of the retainer cap 80 is essentially identical to the retainer cap 46. Retainer cap 80 has an inner threaded surface 84 on its upper end sized to mate with the threads 62 on the lower end of booster holder 28, Figs. 2 and 3. The lower end 86 of cap 80 is basically a hollow cylinder sized to fit over and completely cover the lower end 66 of the boot 44. Between the threaded portion 84 and the smaller diameter upper end 86 is a shoulder 88 adapted to engage the shoulder 68 on the boot 44, Figs. 4 and 5. An opening 90 on the lowermost end of the retainer cap 90 is sized to fit the detonating cord 42 of Fig. 1. It can be seen that if the alternative retainer cap 80 is substituted for the retainer cap 46 of Fig. 1, essentially the entire boot 44 is covered and protected by the retainer cap 80. The retainer cap 80 is particularly useful in wells in which the ambient conditions of pressure,

temperature and gases, such as methane, may cause the boot 44 to swell or lose strength and possible allow borehole fluids to flow between the detonating cord 42 and the boot 44. The retainer cap 80 maintains a close fit of the boot 44 to the detonating cord 42. If any swelling of boot 44 occurs, it will only increase the seal between the boot 44 and the cord 42, since the cap 80 is preferably made of metal which will maintain its dimensions. The retainer cap 80 may have a knurled outer surface to facilitate manual turning during the assembly process described below.

[0037] With reference to the figures, assembly and operation of a detonator system of the illustrated embodiment will be described. Assembly begins with the main firing head 10 which is preferably manufactured from high strength steel heavy wall tubing, or other materials with sufficient strength for use in boreholes. The chamber 14 may be machined to receive a particular electrically fired detonator, but is preferably sized to receive a range of commercially available electrically fired detonators. Typical detonators, such as the above referenced RED-III detonator, are adapted to be mechanically attached to the lower end of the firing sub 18 by a rubber sleeve on the top portion of the detonator 16. An electrical contact on top of detonator 16 makes contact with the center conductor in the firing sub 18 to provide an electrical path to a wireline. A second electrical contact, or ground connection, is made between a conductor on the outer surface of detonator 16 and the inner wall of firing head 10. After the detonator 16 has been attached to the lower end of the firing sub 18, the assembly is lowered into the upper end 12 of firing head 10. The firing sub is mechanically connected by threads 20 and forms a fluid tight pressure seal in the top of chamber 14 by means of the O-ring seals 22. Note that in this embodiment, the lower portion of detonator 16, i.e. the portion containing an explosive material, extends below the chamber 14 and into the lower portion 24 of the firing head 10 which has one

side open. The chamber 14 is therefore not directly exposed to explosive forces produced by detonator 16, and as a result the firing head 10 may be reused several times.

[0038] The next part of the process is assembly of the booster charge holder 28, the booster charge 40, detonating cord 42, boot 44 and cap 46. The detonating cord 42 may be cut to the appropriate length according to the desired operation and type of tool to be bolted to the holes 26 in the lower end of firing head 10. A retainer cap 46 or 80 may then be placed onto the detonating cord 42. Next, the detonating cord 42 is inserted through the boot 44. The end 72 of boot 44 is sized to fit tightly onto the detonating cord 42 and must be stretched to some extent when the cord 42 is inserted. It is desirable to apply a lubricating and preferably water sealing material, such as petroleum or silicone grease, to the outer surface of the detonating cord 42 to facilitate insertion of the cord 42 through the boot 44. It should be inserted until a portion of the cord 42 protrudes from the large end 70 of the boot 44. The open end of the booster charge 40 is then slipped over the end of the cord 42 and crimped onto the cord 42. The cord 42 and booster 40 are then pushed back into the boot 44 until the lower end of the booster 40 is seated in the large end 70 of the boot 44. When seated, a portion of the closed end of booster 40 extends from the boot 44, as shown in Fig. 1.

[0039] It is desirable to apply a lubricating and preferably water sealing material, such as petroleum or silicone grease, to the outer surface of the large tapered end 64 of the boot 44. The large end 64 is then inserted into the lower chamber 36 of booster holder 28. Since the large end 64 of boot 44 is sized for a tight fit into chamber 36, it must be forced in and the grease facilitates the process. The process also applies compressional force on the boot 44 forming a fluid resistant seal between the detonating cord 42, the boot 44 and the inner surface of chamber 36. When properly inserted, the upper end of booster 40 is

positioned adjacent or preferably in contact with the lower surface of bulkhead 38. The cap 46 or 80 is then slid up the cord 42, over the end 72 of boot 44 and threaded onto the threads 62 on the lower end of booster holder 28. The cap 46 or 80 should be tightened to apply compressional force to the shoulder 68 on boot 44 to restrict movement of the boot 44 and booster charge 40 and to maintain the fluid tight seal. If the cap 80 is used, it will also apply compressional forces to the lower end 66 of the boot 44 to maintain its fluid tight contact with the detonating cord 42.

[0040] Seals, e.g. O-ring seals, are then inserted into the grooves 58 on the upper end 30 of booster holder 28 and a lubricating and preferably water sealing material, such as petroleum or silicone grease, is preferably applied to the seals. The upper end 30 of booster holder 28 is then slid over the exposed lower end of the detonator 16 until the upper end 30 seats in the lower end of chamber 14 in firing head 10. At this point, the lower end of the detonator 16 should be adjacent the upper surface of the bulkhead 38. The retaining clip 40 is then inserted into the groove 60 in booster holder 28 and attached to the firing head 10 with screw 50.

[0041] Various safety steps are usually added to the above-described process. For example, the firing sub 18 may be attached to a wireline before it is inserted into the firing head 10. Once connected to the wireline, a firing system should provide a short circuit to keep the detonator 16 in safe condition. A tool, such as a perforating gun may be attached to the holes 26 in the lower end of firing sub 10 before the detonating cord 42 is cut to length.

[0042] Once assembled with a desired tool, the complete assembly may be inserted into and lowered down a borehole by use of a wireline. As the assembly travels down hole it will be immersed in borehole fluids including oil, salt water and various gases. The

pressure will increase with depth and can easily reach thousands of pounds per square inch. The chamber 14 is sealed from exposure to the high pressure fluids at its top by firing sub 18 and seals 22 and at its bottom by the booster holder 28, including seals 32 and the bulkhead 38. The upper chamber 34 of booster holder 28 is effectively an extension of chamber 14 and is also protected from borehole fluids and pressure.

[0043] The lower chamber 36 of booster holder 28 is protected from borehole fluids by the seals formed between boot 44, the detonator cord 42 and the inner surface of lower chamber 36 in booster holder 28. External pressure from borehole fluids urges the detonator cord 42 and boot 44 into the chamber 36, improving the fluid tight seal. The forces do not degrade the performance of the booster 40 and detonating cord 42. The seal however, substantially prevents any borehole fluids from entering the lower chamber 36 or the booster charge 40 where they might otherwise interfere with explosive transfer from the booster charge 40 to the detonating cord 42.

[0044] Once the assembly has reached the selected depth, the detonator may be fired by application of an appropriate signal from a firing system at the surface location of the well through the wireline. The explosion from the detonator ruptures the bulkhead 38 and transfers the explosion to the booster charge 40 which detonates. The detonation of the booster charge 40 initiates detonation of the detonating cord which may transfer the explosion to other explosive components down hole. In the illustrated embodiment, the explosive forces will destroy the booster holder. However, firing head 10 is not directly exposed to the explosive forces in that none of the explosive material is fired within a closed chamber 14 in the firing head 10. As a result, the firing head 10 in this embodiment may normally be reused several times.

[0045] If reuse of firing head 10 is not desired, the chamber 14 could be extended on its lower end so that the entire detonator 16 is contained within chamber 14. The booster holder 28 could be shortened so that the bulkhead 38 is located at the upper end of charge holder 28. This would place the bulkhead adjacent the lower end of the detonator 16 and the booster charge just below the bulkhead. The chamber 14 would still be sealed from environmental pressure and fluids to protect the detonator. However, the forces generated by detonation of the detonator in chamber 14 may damage the firing head 10 sufficiently to prevent its reuse. For example, even a small expansion of the lower end of chamber 14 may prevent forming a fluid and pressure tight seal with a new booster charge holder 28.

[0046] The embodiment described above includes an electrically fired detonator and is conveyed into a borehole and fired by a wireline and wireline firing sub. It is apparent that other types of detonators and other types of conveyance and firing means may be substituted within the scope of the present invention. For example the system may be conveyed into a borehole on coiled tubing. A firing sub connected to coiled tubing may include an electrical power source to fire an electrically fired detonator and may be initiated by hydraulic pressure, a coded acoustic signal, a timer, by a mechanical device dropped or otherwise conveyed down the tubing, etc. A mechanically fired detonator may be coupled to a firing sub on coiled tubing and fired by a pressure pulse or by a mechanical device dropped or otherwise conveyed down the tubing. Such devices may be conveyed downhole on a work string in place of a coiled tubing or wireline. In any of these cases, the firing sub may still provide a fluid and pressure seal for the firing head detonator chamber protecting the detonator from borehole fluids.

[0047] As described above, most of the parts of the described embodiments have approximately cylindrical outer surfaces and inner chambers. Cylindrical shapes are generally preferred in borehole applications and for making threaded couplings or fluid and pressure seals using O-rings. However, the cylindrical shapes are not essential for practicing the present invention. Sealing and coupling arrangements are available for other cross sectional shapes such as square or hexagonal in which the components of the present invention could be made.

[0048] While the present invention has been illustrated and described with reference to particular embodiments and methods of use, it is apparent that various changes and substitutions of parts may be made within the scope of the invention as defined by the appended claims.